Mentoring Advanced Placement
Physics

Topic: Work and equilibration of forces, siphons

Quick Question:

A plastic straw can be driven through a raw potato.

Q: How is this possible and what are the forces involved?

Challenge:

1.) If a tube filled with water connects two buckets of water, what will happen when one bucket is raised above the other?

2.) How does this occur?

3.) Will this still occur if the tube is stretched 20ft into the air? If the process is to continue, what limits tube height?

QQ Solution:

This is fun to demonstrate, and it might even work to bring a potato and straws without prior notice, starting out a meeting by posing the question.

Shoving the straw into the potato will only bend the straw - the plastic is not rigid enough to puncture a starchy root. But, if you pinch over the end of the straw at one end and hold it tightly, air will compress in the straw as it strikes the potato. The radial outward air pressure keeps the straw's walls rigid; a simple but satisfying solution.

Watch your fingers. It may be best to secure the potato on a desk and strike without hands nearby.

Challenge Solution and Discussion:

For demonstration, MAP has a long section of clear plastic tubing and two five gallon buckets. We recommend performing this demonstration near a stair case or balcony where the tube can be raised to considerable height, and also recommend filling one of the buckets with a dye or colored drink mix so that fluid from it can be observed moving through the tube.

1.) Raising one bucket will cause liquid to flow until the surface level of liquid in both buckets is even.

2.) Raising the bucket imparts work on one side of the system. This work is held as an increase in potential energy for all of the liquid in the bucket, and as compression for fluid in the raised tube relative to the stationary side.

Whereas downward forces on both sides of the tube were equal before raising one bucket, there is now a net downward force on the lower bucket's side and a pressure difference across the tube's peak driving water flow.

- A greater vertical length for one side of the tube exposes more mass for gravity to act on. This leads to a greater downward force on that side, similar to a scale with more weights on one arm.

Additional questions for further understanding:

If the peak of the tube is held stationary and one bucket is moved outward and up so that its side of the tube is taught, that tube still contains the same amount of mass in water as it did in the equilibrium state. But, water will begin flowing.

- Ask students if they can see how water flows even though the mass of water in both halves of the tube is equal.

Similarly, if both buckets are left level and a large mass of tubing is held over one side while only a short vertical segment is held over the other, the water still won't flow.

- One side has a large excess mass for gravity to act on, so why won't the water behave like a scale similarly imbalanced?

A: Holding a tube out the side supplies a normal force to the water in it. This adds a vertical force component to the water. In the case where water flows, this vertical force is sufficient to produce and imbalance.

For the case where no water flows, the excess mass is balanced by the vertical component of the normal force. (This can be seen by drawing right triangles and imagining the tube to be a string weight of uniform density.)

3.) This process will occur with the tube 20ft. above the buckets, but will not occur with the tube 34ft. above the buckets.

At 20ft atmospheric pressure is enough to push water into the tube and keep it filled. In equilibrium this pressure is what keeps both sides of the tube from spontaneously emptying.

Above 34ft atmospheric pressure is insufficient to push water into the tube and a vacuum will open, breaking the chain of molecular interactions which transmit force from one side to the other.

- If an extremely small diameter tube is used with very pure water, hydrogen bonding and adhesion may be sufficient to keep the water column intact. At this point the hydrogen bonds are strained and the water is under tension.
- Trees taller than 34ft use this bonding behavior to draw water up to top most leaves and the tension actually leads to a measurable decrease in trunk diameter at times of day when water flow is greatest.

The siphon problem can also be looked at in terms of difference in pressure. At equilibrium, water in the tube positioned at the same level as water in the bucket experiences pressure of one atmosphere. Moving vertically up, every 10cm the pressure decreases by roughly 1%. Since both sides of the tube have similar vertical distances, the pressure reduces by an equivalent amount and at the peak both sides have equally lowered pressure. After raising one side, assuming atmospheric pressure for the opening of both ends of the tube, the longer side will have more vertical distance to lower pressure over and have an even lower pressure at the peak, causing water to flow from the high pressure side to the low pressure side and out.

Alternately, it can be considered that water in the lower side's tube is at atmospheric pressure when level with the surface of water in the upper bucket. At all points below this it is at greater than atmospheric pressure, and thus capable of overpowering the atmosphere and flowing out, into the lower bucket.